Chemistry for Engineers

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Chemistry for Engineers

This book is dedicated to my wife, Shiao-Ping Siao Yen, Ph.D., formerly (1959-1969) at the Mellon Institute (Fellow, Basic Polymer Science Research), currently (1969-present) at the Jet Propulsion Laboratory, California Institute of Technology (Senior Technical Staff), for her support, understanding, and sacrifice.

FOREWORD

The phrase "Think cosmologically, act globally" conveys what I feel regarding the need for engineers to study science. We all live in this vast universe which is ever expanding its limits and challenging human dimensions. But our actions are limited to his global sphere we inhabit, occupy and can reach out for. Thus codes and regulations are an important instrument for guiding the actions of engineers. But what lies beyond and underneath these regulations is science. Thus to truly understand the workings of these processes, our thinking should be oriented towards the laws of the cosmos, the study of science. Science is involved with knowing the nature and origins of matter. At the microscopic level it is called **physics** and at larger and more complex systems, it translates to **biology**. **Chemistry** is the connecting link in between, which defines the integrating reactions and interactions in this chain.

Presently, I cannot locate any book that addresses the needs of engineers when they want to understand the chemistry, or the science which yields the processes they deal with. This was my motivation to write such a book and making available such a resource. I believe that engineers should be trained in basic science because engineering is an applied science, and it should return to science at higher levels of advanced engineering studies. This book aims at bridging the concepts and theory of chemistry with examples from fields of practical application, thus reinforcing the connection between science and engineering.

As a trained chemist and spending years of experience with research institutes, industries and universities in engineering, I identified the various fields of chemistry that will interest engineers. My doctoral training is in synthetic organic chemistry; other graduate experience is in chemical engineering, biochemistry and mathematics. My post doctorate training is in polymer chemistry and geochemistry. During the last four decades of teaching, my research effort has been in environmental engineering intermixed with petroleum and fuel chemistry.

What chemistry to teach engineers? This answer requires some difficult thought. A straight legitimate way to consider the current curriculum for an engineering program (such as BS in general) requires both general chemistry and calculus based general physics, with at least a two semester sequence of study in either area. As per ABET ruling, a number of engineering disciplines do not require even general chemistry. This is sad especially for the senior level of engineers or post graduate engineers. It is indeed disastrous that a well known military leader cannot construct an emergency runway without the supply of cement.

Perhaps the more adequate definition of engineering is from an ancient Chinese scholar, Jia Yi. He claimed nature such as Heaven and Earth is only a testing tool (reactor) for engineers, and that the pursuit of evolution and understanding of life processes is engineering. This reflects that engineering is logically the reasoning to critically resolve the fundamental problems of great importance.

In this book, specialized topics of chemistry are revisited. The first five chapters, Physical Chemistry, Inorganic Chemistry, Organic Chemistry, Analytical Chemistry, and Surface Chemistry are a review of general chemistry covered in first year undergraduate engineering courses.

For materials, metallurgical and mechanical engineering students, material chemistry, polymer chemistry, and inorganic chemistry become important. For bioengineering and agricultural engineering, biochemistry becomes important, and similarly, for geological engineering, geochemistry becomes important. For manufacturing and petroleum engineering, fuel chemistry is essential. For civil engineering, cement chemistry and asphalt chemistry are important. For environmental engineering and chemical engineering, all twelve chapters are required. According to the real needs of the students, the instructors can arbitrarily delete certain topics.

Since this book in intended to be used worldwide without borders, free selection of the material depends on regional need.

Teh Fu Yen

PREFACE

Having decided to go on this project of making a chemistry book for engineers, the main problem faced was deciding what to write. There was no similar treatise which I could select or look at. The first requirement what I thought for a long while is a good review of the necessary chemistry which links high school chemistry and college chemistry and also a short introduction of the chemistry undergraduate major requirement. These are a total of five different subjects – physical chemistry, inorganic chemistry, organic chemistry, analytical chemistry and surface chemistry. Could the basic concepts of these five subjects become sufficient for review of the essential part of chemistry for the need or basic tools for an accomplished engineer?

The next effort is in determining to what extent any subject should be covered. For example, for organic chemistry, there are thousands of important compounds or nomenclature, thousands of chemical synthesis, thousands of named reactions and thousands of important mechanisms. The question is whether any engineer needs to learn these or familiarize with them. So one has to select, shorten and abstract the necessary basic principles for engineers, with limited space to cover the entire subject. One can always be blamed for being arbitrary and subjective. The author's forty years of experience in teaching engineering students and contacts with engineering societies has solved some of the difficulties which were encountered by others.

I would like to thank the policy of the School of Engineering at the University of Southern California to have this chance of imparting global education without borders. I would also like to acknowledge many colleagues and students without whom this book would not be possible. In particular, I express my gratitude to Ngo Yeung Chan, Zixuan Chen, Neelakshi Hudda, Wanda Tan, and Nishant Vijayakumar.

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Credit to Oxford University Press and to C.M.Dobson, J.A.Jerrard and A.J.Pratt, *Foundation to Chemical Biology*, 2001, Fig. 1.2 for Fig. 6-1 ; Figs. 1.7 and 1.8 for Fig. 6-2; Fig. 2.2 for Fig. 6-4; Fig. 2.9 for Fig. 6-8; Fig. 3.2 for Fig. 6-9; Fig. 3.7 for Fig. 6-10; Fig. 3.8 for Fig. 6-11; Fig. 3.11 for Fig. 6-13; Fig. 3.12 for Fig. 6-15; Fig. 3.13 for Fig. 6-16. Credit to Springer-Verlag Inc. and to B.D.Hames and N.M.Hooper, *Biochemistry*, 4th ed., 2000, p. 48, Fig. 4 for Fig. 6-14; p. 137, Fig. 1 and Fig. 6-24; p. 138, Fig. 2 for Fig. 6-25. Credit to Elsevier Science Publishers and D.Koruga, S.Hameroff, J.Withers, R.Loutfy and M.Sundareshan, *Fullerene*, 1993, F: 5. 1-2 (p. 142) for Fig. 6-26 and Fig. 6-27; F: 5. 1-3 (p. 143) for Fig. 6-28; F: 5.24 (p. 150) for Fig. 6-29; F: 5.3-4 (p. 158) for Fig. 6-30. Credit to John Wiley and Sons and to D.Voet and J.G.Voet, *Biochemistry*, 1990, Fig. 32-2 for Fig. 6-31; Fig. 28-34 for Fig. 6-32; Fig. 28-35 for Fig. 6-33; Fig. 32-38 for Fig. 6-33A; Fig. 32-11 for Fig. 6-34; Fig. 32-12 for Fig.6-35. Credit to Cambridge University Press and to K.E.Peters, C.C.Walter and J.M.Moldowan, *The Biomarker Guide*, 2nd ed., II *Biomarkers and Isotopes in Petroleum Systems and Earth History*, 2005; Fig. 12.4 for Fig. 7-9; Fig. 18.85 for Fig. 7-11; Fig. 18.118 for Fig. 7-13; Fig. 19.1 for Fig. 7-14; Fig. 19.16 for Fig. 7-15; Fig. 18.131 for Fig. 7-16; Fig. 18.138 for Fig. 7-17; Fig. 13.63 for Fig. 7-32. Credit to Columbia University Press and to G.Ottonello, *Principles of Geochemistry*, 1997, Fig. 11.14 for Fig. 7-23; Fig. 11.16 for Fig. 7-24; Fig. 11.27 for Fig. 7-26; Fig. 11.29 for Fig. 7-27. Credit to John Wiley and Sons and to G.Faure, *Isotope Geology*, 2nd ed., 1986, Fig. 6.2 for Fig. 7-25. Credit to Cornell University Press and P.-G. de Gennes, *Scaling Concepts in Polymer Physics*, 1979, Fig. 4-1 used for Fig. 9-7. Credit to Nature Publishing Corp. and to J. Klein, *Nature*, **271**, 143, 1978, Fig. 2 used for Fig. 9-8. Credit to John Wiley and Sons and to S.C.Rosen, *Fundamental Principles of Polymer Materials*, 2nd ed., 1993, Fig. 14.1 used as Fig. 9-14; Fig. 14.2 as Fig. 9-15; Fig. 14.4 as Fig. 9-16; Fig. 18.1 as Fig. 9-20; Fig. 18.15 as Fig. 9-23; Fig. 18.20 as Fig. 9-24 and Fig. 18.21 as Fig. 9-25.

CONTENTS

CHAPTER 1

PHYSICAL CHEMISTRY

*P*hysical chemistry is concerned with the study of the physical properties and structure of matter using the laws of chemical interaction. Generally, the purpose of physical chemistry is threefold:

- to collect the appropriate data required to define the properties of matter
- to establish the energy relations in physical and chemical transformations
- to predict the extent and rate of the transformation taking place and identify its controlling factors

For our concern as engineers, the principles of physical chemistry could lead to an understanding of such concepts as the identification of compositions in aqueous solutions, the effects of additives on water purification, the extent and prevention of corrosion in piping, and so on. There are two common approaches to understanding physical chemistry. The first is the **synthetic approach**, which begins with the study of the structure and behavior of matter from subatomic particles, electrons, and nuclei, to atoms and molecules, and then proceeds to their